Facility Comparison and Evaluation Using Dual Ridge Horns

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***Abstract*— In the frame of the activity "Antenna Measurement Techniques and Facility Sharing" of the EU network ACE "Antenna Centre of Excellence" [1] substantial attention has been devoted to perform a series of antenna measurement facility comparisons. The activities have been performed using SATIMO dual ridge horns in L, S and C band (SH800) and in Ku and Ka band (SH2000) [2-5].**

This paper discuss the activities and preliminary results of the comparison campaign in Ku and Ka band using the SATIMO dual ridge 2-32GHz horn (SH2000) shown in Fig. 1. The activities include data collected from both ACE and non ACE participants in Europe and US during a 3 year period.

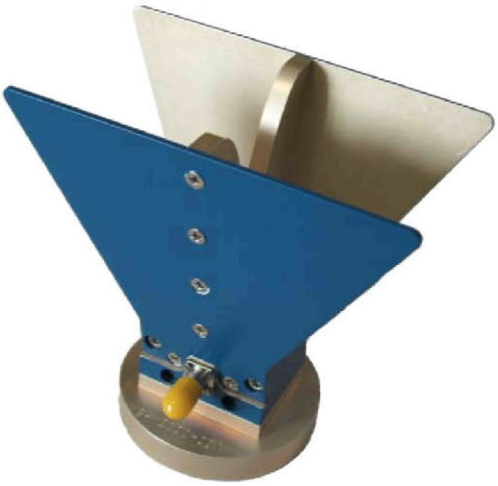

Fig 1: SATIMO SH2000 dual ridge horn (2-32GHz).

I. Introduction

Comparative measurements based on high accuracy reference antennas and involving different antenna measurement systems are important instruments in the evaluation, benchmarking and calibration of the measurement facilities. Regular inter comparisons are also an important instrument for trace-ability and quality maintenance. These activities promote and document the measurement confidence level among the participants and are an important prerequisite for official and unofficial certification of the facilities.

The comparative measurements discussed in this paper have been performed at 8 selected frequencies in Ku and Ka band involving 11 different test facilities. The comparison of such a large amount of measured data is unfeasible by inspection of pattern differences and should not be limited to studying bore sight or peak differences alone [6]. Different approaches have been implemented to overcome this problem.

The measured results are elaborated with the aim of finding the "true" radiation pattern of the antenna. This is done by a weighted average approach in which the weights are inverse proportional to the declared uncertainties of the facilities. From this elaboration the peak gain, peak directivity and a high fidelity reference pattern is defined. The effective difference between the measured and the reference pattern can be expressed in a single value if calculated as the standard deviation of the weighted differences between the sets of data. This allows the easy comparison of a large number of measurements by simple inspection or visualisation [2-5].

II. Participating Facilities

The SATIMO dual ridge horn SH2000 has been measured by both ACE and non-ACE members in Europe and US. The geographical distribution of the participating institutions is shown in Fig 2.

Fig 2: Facilities involved in facility comparison using SH2000.

A complete list of the participating facilities in this campaign is shown in Table I. Three different types of antenna test ranges are represented: Spherical Near Field range (SNF), Far Field ranges (FF) and Compact ranges (C). Although not a statistically significant representation, the number of institutions and the even distribution of facilities allow to derive important comparative information about the different antenna measurement methods. The measured data from UPC, SES, GTRI and SAAB are still in post-processing.

TABLE I
Participating Institutions, Acronym, Country of Origin and Measurement Configuration.

Acronym	*Name*	*Country*	*System*
SATIMO	SATIMO	France	SNF
DTU	Technical University of Denmark	Denmark	SNF
UPM	Technical University of Madrid	Spain	SNF
UPC	Technical University of Catalunya	Spain	SNF
SES	SAAB Ericsson Space	Sveden	SNF
FTR&D	France Telecom	France	FF
GTRI	Georgia Tech Research Institute	USA	FF
IMST	IMST GmbH	Germany	FF
XLIM	University of Limoges/CNRS	France	C
THALES	Thales Alenia Space	France	C
SAAB	SAAB Group	Sveden	C

III. Test Antenna

The SH2000, 2-32GHz, dual ridge horn combines a stable gain performance and low VSWR with wide band frequency operation. The horn is single linearly polarized with high cross-polar discrimination and is often used as reference antennas for gain calibration of antenna measurement systems or as wideband probes in classical far field test ranges.

The horn is specifically designed to avoid excitation of higher order modes in the aperture and to maintain a well-defined smooth radiation pattern in the direction of the boresight axis throughout the operational bandwidth. The horn is equipped with a high precision female 3.5mm connector intermateable with SMA and K connectors.

IV. Test Configuration and Design

Experiences from previous facility comparisons [2-5] have shown that the measured results are sensitive to the measurements configuration and in particular the type of positioner. To improve the correlation and independence from measurements configurations the test antenna has been equipped with a small absorber plate (250 x 250mm) covering the mechanical interface as shown in Fig 3.

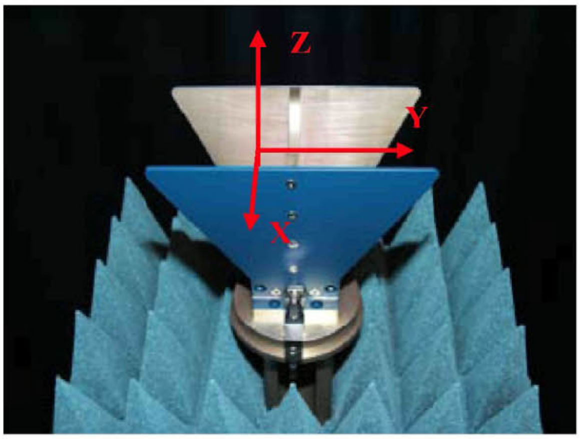

Fig 3: SATIMO SH2000 Dual Ridge Horn with absorber plate in test configuration. The reference coordinate system is shown on the antenna.

As is preferable for comparative testing the SH2000 test antenna has very low losses due to the fully metallic design and low loss connector. However, to avoid differences in the measurement configurations from different cable positions, the antenna has been equipped with a 90deg bend and short piece of low loss cable as shown in Fig 4. The bend and short cable adds additional losses to the measured antenna.

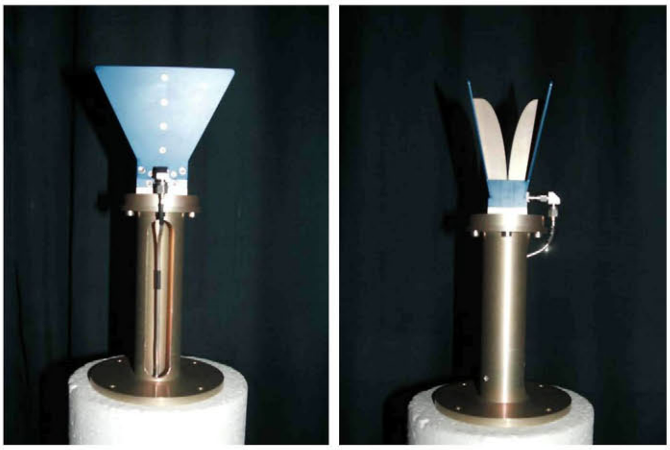

Fig 4: For the facility comparison campaign the SH2000 was equipped with a 90deg bend a short low loss cable to avoid differences in the measurements conditions due to different cable positions.

The SH2000 Horn, is fastened and aligned with the metallic support by 4 screws and the polarisation alignment is determined by a precision pin in mechanical interface plate (accuracy= ± 0.01 deg on azimuth). The 90° bend is attached to the horn and to the cable. The cable goes inside the support.

V. Derivation of High Accuracy Reference Data

Uncertainty analysis of measured data is not an exact science but nevertheless an important tool to determine error boundaries. Very accurate reference data can be derived from a statistical treatment of measurements on the same reference antenna performed in the same condition in different ranges as explained in [7]. The reference data is calculated as the weighted mean of each data entry where the weights are inverse proportional to the estimated uncertainty [2-5], [7-8]. The data with the lowest estimated uncertainty receive the highest weight. The uncertainty associated with the improved reference data can be determined from the weighted mean of the uncertainties. The formulas for the weighted average data value X_{typ} and associated uncertainty u_{typ} using a linear scale are illustrated below:

$$X_{typ} = \frac{\sum_{i=1}^{N}\left(\frac{x_i}{u_i^2}\right)}{\sum_{i=1}^{N}\left(\frac{1}{u_i^2}\right)} \qquad u_{typ} = 1 + \frac{1}{\sqrt{\sum_{i=1}^{N}\frac{1}{(1-u_i)^2}}}$$

In the case of N independent measurements each with the same uncertainty the above formulas reduces to the well known result that the average value has improved uncertainty by a factor square root of N.

It is acknowledged that practical values of N are too few in a strictly statistical sense. It is also evident that while most uncertainty contributions can be considered uncorrelated in different ranges – other contributions will be correlated to some degree. Examples are references antennas calibrated in the same range or uncertainties linked to methods or processing software.

The facilities have highly different approached in defining uncertainties associated with the measurements. In order to compare and process the data the indicated uncertainties have been converted into a normal probability distribution with standard deviation σ, using a divisor. To perform the conversion for rectangular distribution of probability the divisor is equal to 1.73, for triangular distribution it corresponds to 2.45 [9]. Since the uncertainty estimates were made not according to the common rules, the obtained reference values may not represent optimum reference data, but its accuracy is improved due to the averaging of independent results. The converted 3σ uncertainty values for all facilities are shown in Table II.

TABLE II

Converted 3σ Peak Gain Uncertainty in dB for each facility.

Freq [GHz]	SATIMO	DTU	UPM	FT R&D	IMST	XLIM	THALES
10.95 11.70 12.75 14.50	0.800	0.342	0.260	0.555	0.300	0.450	0.210
18.20 21.20	------	0.399	0.268	0.555	0.300	0.450	0.210
27.50	------	------	0.268	0.555	0.300	0.450	0.210
31.00	------	------	0.268	0.555	0.500	0.450	0.210

VI. Pattern Comparison

The traditional comparison of measured data is often based on boresight gain and directivity values [6]. However, the measurement differences and their sources are often better understood by direct inspection and comparison of the patterns. Measured copolar and cross polar patterns at 10.95GHz and 11.70GHz are compared with the reference pattern in Fig. 5 to Fig. 8. The reference pattern has been determined by the weighted average approach. The 45° cuts in which the off axis cross polar component is an important measure of correlation have been selected.

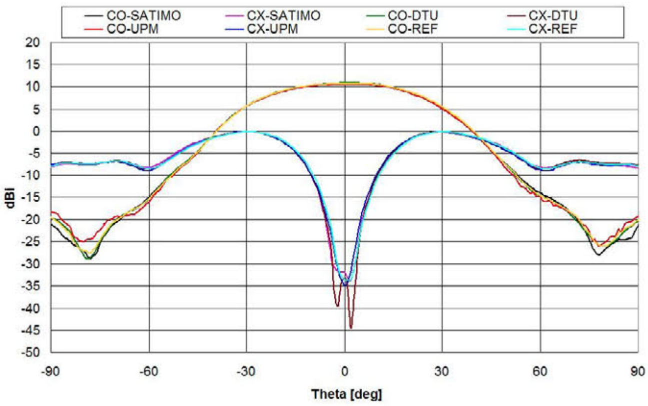

Fig 5: Measured gain pattern @10.95. Reference, SATIMO, DTU, UPM measurements.

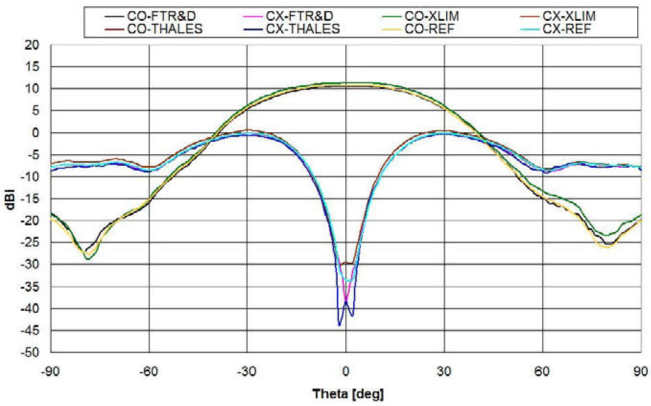

Fig 6: Measured gain pattern @10.95. Reference, FTR&D, XLIM, THALES measurements.

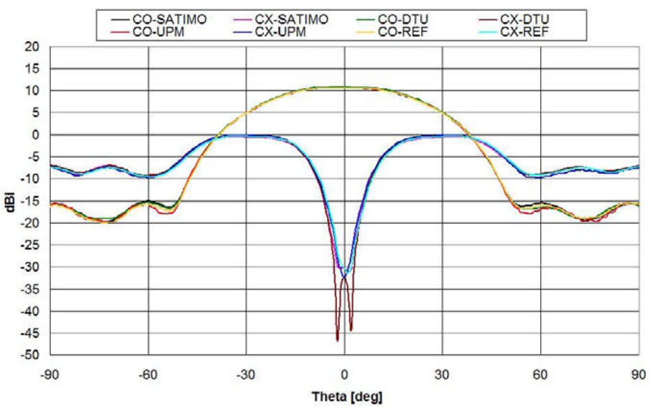

Fig 7: Measured gain pattern @11.70. Reference, SATIMO, DTU, UPM measurements.

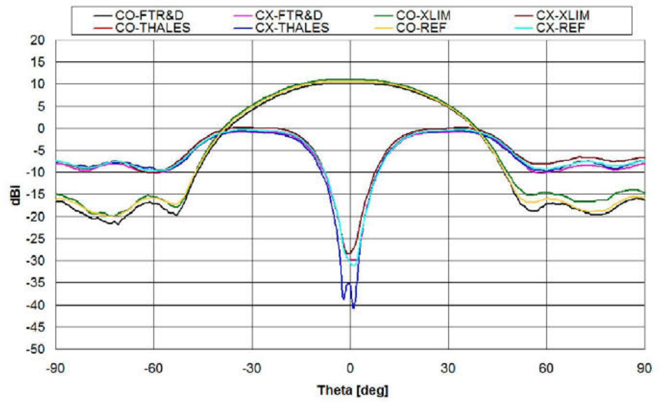

Fig 8: Measured gain pattern @11.70. Reference, FTR&D, XLIM, THALES measurements.

VII. Boresight Gain Comparison

The measured boresight gain from the individual facilities are shown in Table III at 8 frequency points. Gain is defined according to the IEEE definition [10] and using Ludwig III for the polarisation definition [11]. For each frequency the weighted average gain and corresponding uncertainty is shown. The difference between the individual measurements and the reference values determined by the weighted average approach are illustrated in Fig. 9.

TABLE III
Measured Gain Values at Seven Facilities, Weighted Average Gain and Associated Uncertainty.

Freq [GHz]	10.95	11.70	12.75	14.50	18.20	21.20	27.50	31.00
SATIMO	10.58	10.53	11.09	11.81	----	----	----	----
DTU	10.78	10.75	11.20	11.78	12.53	12.90	15.02	16.43
UPM	10.56	10.52	11.15	11.92	12.46	12.76	14.68	15.89
FTR&D	10.56	10.14	10.80	11.68	12.33	12.49	14.94	15.66
IMST	10.53	10.36	11.14	11.78	12.45	12.79	14.83	15.68
XLIM	11.30	11.00	11.50	11.80	12.70	13.40	14.60	15.90
THALES	10.53	10.48	10.97	11.76	12.62	12.86	14.88	15.78
Weighted Average Gain	10.69	10.54	11.12	11.79	12.52	12.87	14.79	15.78
Uncertainty (3σ)	0.124	0.124	0.124	0.124	0.128	0.128	0.135	0.144

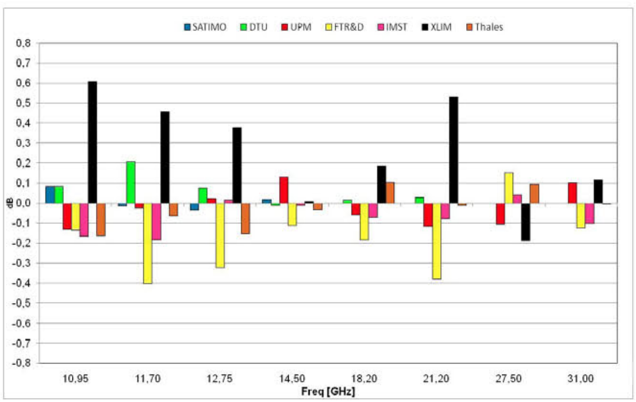

Fig 9: Gain difference, individual measurements with respect to the calculated weighted average.

VIII. Statistical Data Comparison

The traditional comparison of measured data is based on boresight gain and directivity values. However, sources of differences are often better understood by comparison of the patterns. The direct comparison of large amount of measured pattern data is unfeasible by inspection of pattern differences alone. Therefore a statistical approach has been implemented that allow the comparison of data in a simple form.

The statistical approach concerns the 45° forward cone of the radiated co and cross-polar patterns. This angle has been determined somewhat arbitrary but for the SH2000 in Ku and Ka band this angle include field levels from 10 to 25 dB below the peak. The Ludwig III [11], co and cross polarised components are treated separately since the cross polar values include 2 cuts in 45° and 135° while the copolar values include 4 cuts.

Ideally comparison against a reference pattern should be based on a reference pattern which can be considered error free. However, as such a reference is not available for the present comparison it is of interest to define a reference pattern based on the measured radiation patterns to which a high degree of confidence can be attributed. The reference data is calculated as the weighted mean of each data entry where the weights are inverse proportional to the estimated uncertainty [2-5], [7-8].

From the reference pattern the standard deviation of the differences for each measurement and in each direction is calculated in which the difference is weighted by the level in that direction with respect to the peak. This value expresses the effective variation over the 45° forward cone giving an indication of the measurement error level in a single value. The procedure is expressed in the following formula, where directivity data are on linear scale:

$$\left(\frac{Dir_{Co,Cx} - Dir_{REFCo,Cx}}{Dir_{REFCo,Cx}}\right)\left(\frac{Dir_{Co,Cx}}{Dir_{CoBoresight}}\right)$$

The resulting number express the equivalent signal-to-noise level in which all deviations with respect to the reference pattern has been converted into an equivalent "noise". The calculated copolar and cross polar standard variation for each facility with respect to the weighted mean reference pattern is shown in Fig 10 and Fig 11.

The standard deviation σ is very useful to quantify the range in which measurements errors are distributed. It expresses the 68.3% confidence that the measurements error is within this level. The 99.7% confidence level is 3σ. The standard deviation expresses only the variation, but it does not consider a general shift. This also mean that this value "clean" the comparison from differences caused by pattern difference in the antenna back-lobe that are often due to differences in the measurement set-up. The impact of this is often very small in high gain measurements but can be a significant contribution when comparing medium and low gain antennas as in this case.

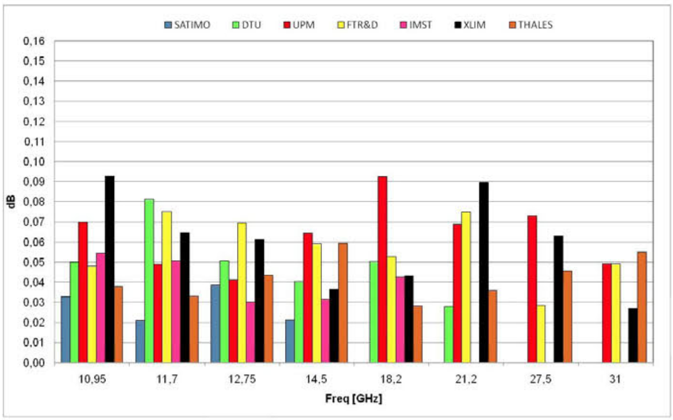

Fig 10: Copolar standard deviation calculated from weighted mean reference patterns in 4 cuts in forward 45° cone.

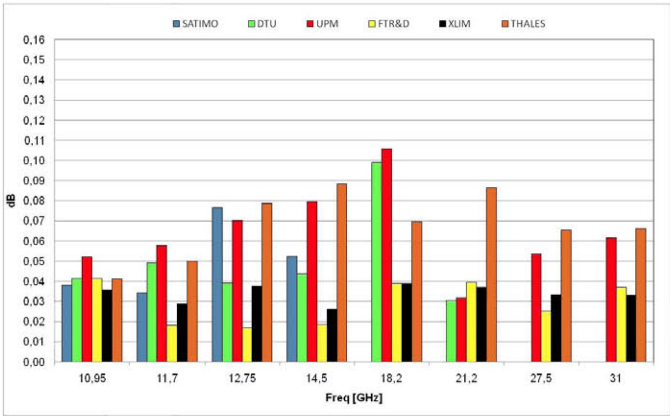

Fig 11: Cross polar standard deviation calculated from weighted mean reference patterns in 2 cuts in forward 45° cone.

IX. Conclusions

The comparison of boresight gain between individual measurements and the reference based on the weighted average approach show that each institution is performing well within the declared uncertainty budgets. This is an indication that the techniques currently used for determining errors bounds on antenna measurements can be considered conservative for "well performed" measurements and could be revised and relaxed. Some initial work in this area has been performed in the frame of ACE [1, 5]. Additional research should be performed to modernise and harmonise the techniques for determining antenna measurement error budgets.

Acknowledgment

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